OG 1.2-2

THE ISOTOPIC COMPOSITION OF LOW ENERGY COSMIC RAYS

R.A. Mewaldt, J.D. Spalding, E.C. Stone, and R.E. Vogt
California Institute of Technology
Pasadena, California 91125
U.S.A.

ABSTRACT

We report new high-resolution isotope measurements of B, C, N, O, and Ne nuclei with ~ 5 to ~ 140 MeV/nuc. These observations extend the study of cosmic ray isotopes to lower energies than before, and provide new information on the isotopic composition of the anomalous cosmic ray component.

1. Introduction: Previous studies have found that the elemental composition of quiet-time cosmic rays undergoes a sudden change below ~ 30 MeV/nuc as the modulated galactic cosmic ray (GCR) component merges with the anomalous cosmic ray (ACR) component, composed of enhanced fluxes of He, N, O, and Ne. We examine the isotopic composition of the GCR and ACR components in an effort to gain new clues to the origin of these low energy nuclei.

2. Observations: The bulk of the observations reported here were made with the Caltech experiment on ISEE-3 during restricted quiet-time periods from 8/13/78 to 12/1/78 (see Ref. 1 for details of the analysis method). Figures 1 and 2 show the observed mass distributions in two energy intervals, where the mass resolution ranges from 0.07 to 0.23 amu. Table 1 summarizes our ISEE results and also includes IMP-7 data from 9/72 to 6/78, extending earlier work[2].

Figure 3 compares our measured isotope ratios with other selected observations and with GCR propagation and solar modulation calculations

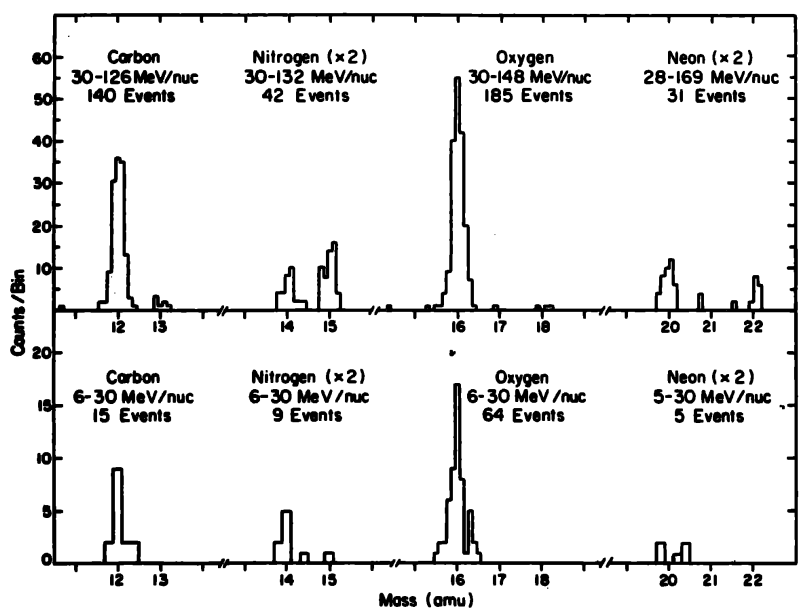

Fig. 1: Observed mass distributions - ISEE data.

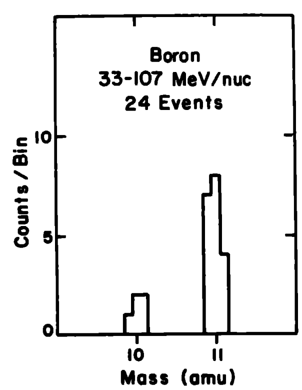

Fig. 2: Boron mass distribution.

(M.E. Wiedenbeck, private communication). The calculations assume an escape length $\lambda = 5.5 g/cm^2$; solar modulation with Φ = 300 MeV/nuc; and standard cross sections. Solar system[17] isotopic abundances are assumed for the source, except for $^{22}Ne/^{20}Ne = 0.4$.

TABLE 1 - MEASURED ISOTOPE RATIOS

Isotope Ratio	Energy Interval (MeV/nuc)	Observed Ratio*
$^{10}B/B$	33-107	$0.19^{+.11}_{-.05}$
$^{13}C/C$	30-126	$0.052^{+.029}_{-.011}$
	5-30	≤ 0.11
$^{15}N/N$	30-132	0.63 ± 0.7
	5-30	$0.11^{+.19}_{-.11}$
	6-13†	≤ 0.19
$^{17}O/^{16}O$	30-148	$0.01^{+.02}_{-.01}$
	6-30	≤ 0.03
	7-12†	≤ 0.06
$^{18}O/^{16}O$	30-148	$.018^{+.017}_{-.006}$
	6-30	≤ 0.03
	7-11†	$0.03^{+.03}_{-.01}$
$^{22}Ne/^{20}Ne$	78-169‡	$0.49^{+.39}_{-.11}$
	5-28	≤ 0.36

* 68% confidence intervals or 84% confidence limits.
† IMP-7 data
‡ from Ref. (1)

3. Galactic Cosmic Ray Isotopes: Our higher energy (> 30 MeV/nuc) results for $^{13}C/C$, $^{18}O/^{16}O$, and $^{22}Ne/^{20}Ne$, and also for $^{17}O/^{18}O$ and $^{10}B/B$ (not plotted) are consistent with the calculations and with most of the other results shown. However, our high energy $^{15}N/N$ ratio is significantly ($\sim 3\sigma$) greater than the calculation, as are several other recent observations. This discrepancy suggests that unless ^{15}N is enhanced at the GCR source, the propagation model (or its parameters) need revision. Although reducing ^{15}N at the source improves the agreement with the isotopic ratio, a further constraint on the model is the observed element ratio $N/O = 0.25 \pm .01$. Thus, Guzik[3] has suggested revised cross-sections for N production. Assuming $\lambda = 5.5 g/cm^2$ and Φ = 220 MeV/nuc, he reproduces his own observations of $^{15}N/N = 0.47$ and $N/O = 0.25$, taking $^{14}N/O = 0.07$ at the source without the need for an enhanced ^{15}N. However, our own observations and others in Figure 3 find even greater $^{15}N/N$ ratios. Since increases in both solar modulation (Φ) and escape length (λ) result in larger $^{15}N/N$ and N/O ratios, we have scaled Guzik's calculations, taking into account the sensitivity to λ and Φ. For example, if $\lambda \leq 7 g/cm^2$ and $\Phi \leq 400$ MeV/nuc, we find that $^{15}N/N > 0.56$ (84% confidence) and $N/O = 0.25 \pm .01$ can be achieved only if $^{14}N/O$ at the GCR source is ≤ 0.04. This is to be compared to the solar value $^{14}N/O = 0.12$. $^{15}N/N$ values > 0.6 can be achieved with $N/O \approx 0.0$ at the source, but this fails to produce the observed N/O ratio.

4. The Isotopic Composition of the Anomalous Component: Below ~ 30 MeV/nuc the quiet-time spectra of N, O, and Ne are dominated by the ACR component. According to the model of Fisk *et al.*[20], the ACR isotopic composition would reflect that of the *local* interstellar medium (ISM) rather than that of the GCR. Although the isotopic composition of neon in the local ISM is unknown, interstellar molecule studies suggest that the N and O composition is similar to that of the solar system. We find that ACR N and Ne have significantly different isotopic composition than at higher energies. For $^{15}N/N$ there is less than a 0.1% probability that our 6-13 MeV/nuc IMP-7 result is consistent with $^{15}N/N > 0.5$. Our low energy ISEE data confirm this ($^{15}N/N < 0.5$ with 99% confidence). For $^{22}Ne/^{20}Ne$ we find the 5-28 MeV/nuc ratio to be less than the

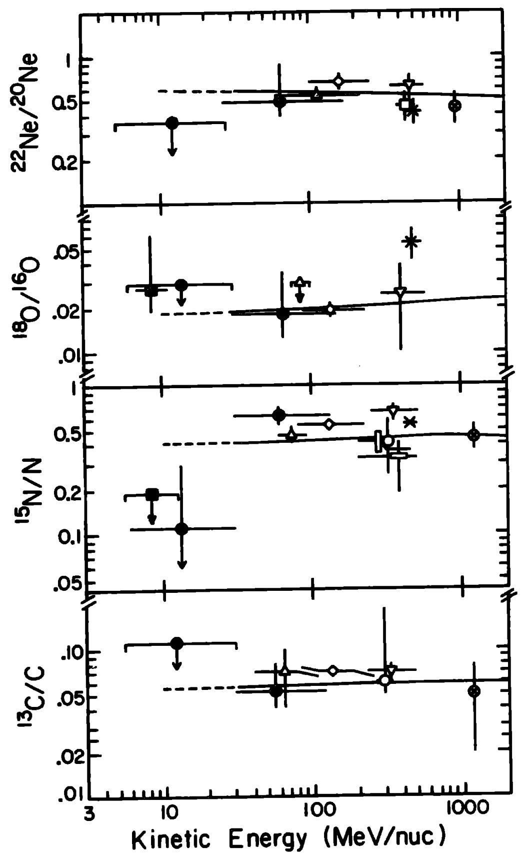

Fig. 3: Measured and calculated GCR isotope ratios. ● This work, ISEE-3; ■ This work, IMP-7; △ Refs. 3-4; ◇ Refs. 5-7; ✱ Ref. 8; ⊗ Refs. 9-10; ▯ Ref. 11; ▭ Ref. 12; ▽ Refs. 13-14; □ Ref. 15; O Ref. 16. Data points with arrows are upper limits.

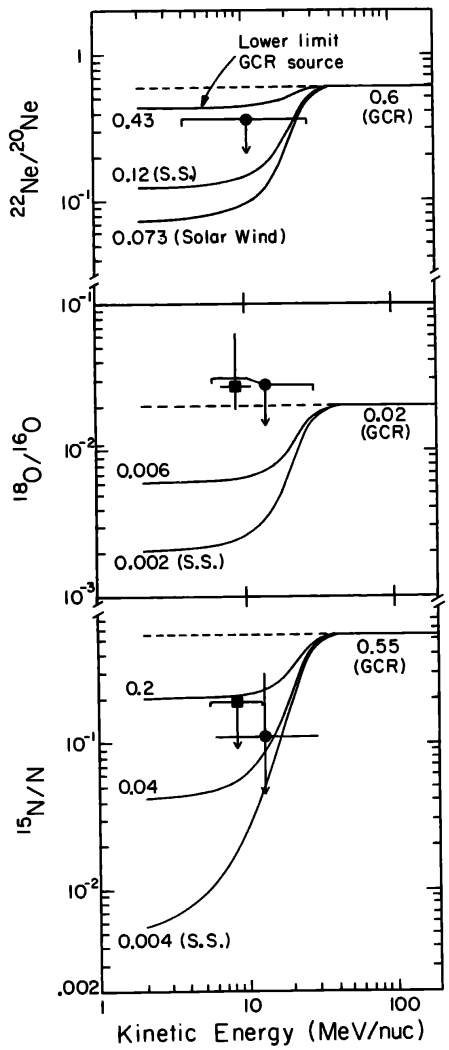

Fig. 4: Comparisons of the observed ARC composition with calculated curves that assume various ACR compositions (labeled on curves), including the solar system[17] value.

~100 MeV/nuc value of 0.6 with 90% confidence (see also Ref. 19).

The curves in Fig. 4 show the expected energy dependence of the isotopic composition that results from adding the ACR and GCR contributions for various assumed ACR compositions. Comparisons of the observations with the curves indicate the range of ACR source compositions that are allowed. For N, we conclude that the ACRs have $^{15}N/N < 0.2$, a factor of ~3 less than we observe for slightly higher energy GCRs. For O on the other hand, our IMP $^{18}O/^{16}O$ ratio for the ACRs (based on two ^{18}O's) is consistent with the GCR component. If verified by other measurements (our ISEE data show only that $^{17}O/^{16}O$ and $^{18}O/^{16}O$ are < 0.03 for the ACRs) this ^{18}O result would be surprising, since GCR ^{18}O is mainly of secondary origin. For neon, our upper limit is inconsistent with both high energy GCR neon and with GCR source neon[5]. The inconsistency with GCR source neon is significant in view of recent models in which the source of galactic cosmic rays is the ISM, also a proposed source of the anomalous component. One possibility might be an inhomogeneous ISM composition.

In summary, we have found further evidence for an energy-dependent isotopic composition at low energies, thereby placing new restrictions on the composition and origin of the ACR component. We find no strong evidence for an exotic isotopic composition; indeed, with the possible exception of ^{18}O/^{16}O, our ACR results are entirely consistent with the interstellar neutral origin proposed by Fisk et al.[20]. If this model is correct, future measurements of this kind may provide a direct measure of the isotopic composition of the local ISM, providing a unique opportunity to study the evolution of the solar neighborhood.

Acknowledgements: We thank Dr. M.E. Wiedenbeck for the use of his GCR propagation calculations. This work was supported in part by NASA under contracts NAS5-11066 and NAS5-20721 and grant NGR 05-002-160.

References

[1] R.A. Mewaldt, J.D. Spalding, E.C. Stone and R.E. Vogt, Ap.J. 235, L95, 1980.
[2] R.A. Mewaldt, E.C. Stone, S.B. Vidor and R.E. Vogt, Ap.J. 205, 931,1976.
[3] T.G. Guzik, submitted to Ap.J. 1980.
[4] M. Garcia-Munoz, J.A. Simpson and J.P. Wefel, Ap.J. 232, L95, 1979.
[5] M.E. Wiedenbeck and D.E. Greiner, Phys. Rev. Lett., in press, 1981.
[6] M.E. Wiedenbeck and D.E. Greiner, this conference, Paper OG1.2-4.
[7] M.E. Wiedenbeck, D.E. Greiner, F.S. Bieser, H.J. Crawford, H. Heckman and P.J. Lindstrom, 16th Int. Cosmic Ray Conf. (Kyoto) 1, 412, 1979.
[8] W.R. Webber, J. Kish and G. Simpson, Op.Cit. 1, 424, 1979.
[9] R. Dwyer and P. Meyer, Op.Cit. 12, 97, 1979.
[10] R. Dwyer, Ap.J. 224, 691, 1978.
[11] A. Buffington, C.D. Orth and T.S. Mast, Ap.J. 226, 335, 1978.
[12] C. Bjarle, N-Y Herrström, L. Jacobson, G. Jönsson and K. Kristiansson, 15th Int. Cosmic Ray Conf. (Plovdiv) 1, 313, 1977.
[13] A.J. Fisher, F.A. Hagen, R.C. Maehl, J.F. Ormes and J.F. Arens, Ap.J. 205, 938, 1976.
[14] F.A. Hagen, A.J. Fisher and J.F. Ormes, Ap.J. 212, 262, 1977.
[15] P.S. Freier, J.S. Young and C.J. Waddington, Ap.J. 240, L53, 1980.
[16] J.F. Zumberge, Caltech Ph.D. Thesis, 1981.
[17] A.G.W. Cameron, Harvard University preprint #1357, 1980.
[18] M. Garcia-Munoz and J.A. Simpson, 16th Int. Cosmic Ray Conf. (Kyoto) 1, 270, 1979.
[19] W.R. Webber, 14th Int. Cosmic Ray Conf. (Munich) 12, 4233, 1975.
[20] L.A. Fisk, B. Kozlofsky and R. Ramaty, Ap.J. 190, L35, 1974.